Predicting Falls in Community-Dwelling Older Adults: A Systematic Review of Task Performance-Based Assessment Tools

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Abstract

Introduction

Falls among community-dwelling older adults are a common yet often preventable occurrence. Clinicians frequently use task-based assessment tools to evaluate clients' balance and mobility with the aim of predicting falls and providing targeted fall prevention interventions, but no consensus exists on the optimum tool(s) to use for this purpose. This review aims to identify the task-based assessment tools that can best predict falls among community-dwelling older adults.

Methods

Online databases Academic Search Complete, AMED, Biomedical Reference Collection: Expanded, CINAHL Plus, MEDLINE, General Science, and SPORTDiscus were searched from 1983 to 2013 to identify prospective studies assessing the performance of specific tasks in order to predict falls. Following screening, the methodological quality of studies included for review was appraised using a checklist based on the Critical Appraisal Skills Programme tool for cohort studies [1].

Results

Thirty-seven studies, dating from 1996 to 2013 and largely of high methodological quality, were included in this review. A range of task performance-based assessment tools suitable for use in both clinical and laboratory settings were identified.

Conclusions

Strong evidence in favour of using the Timed Up-and-Go test, Five Times Sit-to-Stand test and assessments of gait speed to predict falls among this population in clinical settings was found, along with weaker evidence for tests of standing balance and reaching task performance. Laboratory-based assessments of postural sway and gait variability were also found to predict falls. Incorporating the

recommended assessment tools into comprehensive assessments of community-dwelling older clients can lead to improved falls prediction by clinicians.

Introduction

Falls are prevalent among community-dwelling older adults. Approximately one-third of those aged 65 years and over fall each year, increasing to about 50% among those aged 85 and over [2]. These falls can have negative consequences for the individual, such as physical injury and functional decline, and also can result in increased health service usage [3]. Fortunately, a number of interventions have been shown to reduce the incidence of falls in this population [4, 5], particularly exercise to improve balance, mobility and strength deficits [6, 7]. Evidence suggests that interventions targeting high-risk groups can prevent more falls and be more cost-effective than those aimed at the general population [8, 9]. Therefore, it is imperative that clinicians can identify those at risk of falling to provide appropriate targeted interventions.

In order to achieve this, it is necessary to have an accurate and objective method for assessing an individual's fall-risk. Since the causes of falls among older adults are multifactorial in nature, it follows that overall fall-risk is best estimated using a comprehensive approach to assessment. This usually incorporates the client's medical history, demographic information, a physical assessment including assessments of balance and mobility, and measures of psychosocial factors that are related to fall-risk [10].

To assess balance and mobility, clinicians often use assessment tools that evaluate the performance of various functional tasks [11], and a number of standardised assessment tools have been developed with the aim of predicting falls based solely on task performance [12]. The range of assessment tools available can present a challenge to clinicians when deciding which tools are most appropriate for use in their practice, and no clear evidence supporting the use of specific tools over others has been demonstrated [13]. Important factors that determine how clinicians select an assessment tool include its applicability to the given population, its validity and reliability, the feasibility of conducting the assessment given the space, time and equipment available, and its value in terms of predicting falls [14]. Using assessment tools that can accurately predict falls enables clinicians to be more efficient in their practice, as these tools will contribute more useful information to aid clinical decision-making, can help to identify those in need of intervention in a timely manner, and also serve as informative outcome measures [14].

The aim of this review is to identify which measures of task performance can best predict falls among community-dwelling older adults. By focusing on measures of task performance only, the findings of this review will help clinicians to select the best performance-based predictors of falls from the many available to include in their overall assessments, thereby improving their efficiency. It will also benefit researchers who wish to make advancements in the area of falls prediction.

Methods

The literature search was carried out in May 2013.The following databases were searched from 1983 to 2013: Academic Search Complete, AMED, Biomedical Reference Collection: Expanded, CINAHL Plus, MEDLINE, General Science, and SPORTDiscus. The search terms used were 'falls predict*' AND 'community' AND ('older adults' OR 'elderly') AND 'physical performance'. Articles were also sourced via reference lists of relevant articles. In order to meet the aim of determining the ability of the task performance-based assessment tools identified to predict falls, only prospective cohort studies were reviewed. Articles were excluded if they were not available in English, were not full text peer-reviewed articles, did not include a measure of task performance, did not measure falls incidence, related to populations with specific conditions only or populations other than community-dwelling adults aged 60 years or over. A second reviewer was consulted if queries arose regarding the inclusion or exclusion of articles.

Results

Thirty-seven studies, dating from 1996-2013, which investigated tools for assessing task performance in relation to falls incidence were identified. The screening process is displayed in Figure 1.

Insert Figure 1 here.

For the purpose of this review, the assessment tools identified were divided into two categories: clinic-based assessments and laboratory-based assessments. Clinic-based measures were defined as those which can be carried out in usual clinical settings, whereas laboratory-based measures were those which required specialist equipment predominantly available in research settings or highly specialised clinical settings. Twenty studies utilised clinic-based measures only, 10 studies included measures from both categories, while 7 studies examined laboratory-based measures only. Summaries of each of the studies reviewed, including outlines of the assessment tools used, are presented in Table 1.

Insert Table 1 here.

A number of measures with the potential to predict falls incidence based on task performance in clinical settings were identified. The most frequently observed measures were the Timed Up-and-Go Test (TUG) (13 studies), Five Times Sit-to-Stand Test (FTSS) (10 studies), assessments of standing balance (9 studies), gait speed measurement (8 studies), and the Berg Balance Scale (BBS) (6 studies). Seven studies examined laboratory-based assessments only, with a further 10 studies including a combination of laboratory and clinic-based assessments. The most frequently-observed laboratory measures were those examining postural sway and gait analysis.

Methodological Quality

To facilitate appraisal of the studies reviewed, a checklist based on the Critical Appraisal Skills Programme (CASP) tool for cohort studies was used [1]. This checklist appraised each study based on the clarity of its focus, the use of an appropriate methodology, a clear and appropriate recruitment strategy, the inclusion of fall-risk measures, the use of a valid and reliable method of reporting falls, the consideration of confounding factors (either in design or analysis), a sufficient follow-up period, the significance and accuracy of results and the applicability of the findings to an older community-dwelling population. Most studies were of high methodological quality, meeting all or almost all of the checklist criteria. Due to the inclusion and exclusion criteria used for this review, all studies were clear in their aims, used an appropriate study design and were applicable to the population of interest. The most commonly identified weakness were inadequate or unclear participant recruitment, the use of suboptimal falls incidence reporting methods and poor consideration of confounding factors.

The majority of studies recruited large samples, although 13 studies had sample sizes of less than 100 participants, including one preliminary study with only 13 participants [15]. Fall-risk was evaluated using multiple measures in most studies. Although only measures of task performance were evaluated in this review, many studies included measures of other factors potentially associated with fall-risk as part of their battery of assessments e.g. physical activity [16], executive function [17], falls efficacy, depression and anxiety [18]. Falls incidence measurement was identified as a potential source of bias, since 11 studies relied on recall-based methods of recording falls. Such methods can lead to significant underreporting of falls among older adults, and the use of falls calendars or diaries is preferable [19]. Factors such as age, sex, and falls history were identified as potential confounding factors in determining fall-risk, and were accounted for in various ways. Zhang et al. [20] altered their study design to exclude those with a recent history of falls at baseline. Other studies accounted for confounding factors in their analyses e.g. by creating subgroups according to baseline fall status [21], by creating multivariate logistic regression models to account for many factors [17], or by using classification and regression tree analysis to partition the sample into optimal subgroups [18]. Most studies monitored outcomes over a sufficient length of time, with follow-up periods greater than 6 months in all but 5 studies [22-26].

A notable methodological feature of all studies reviewed was the heterogeneity in the methods of reporting results. Most studies calculated Rate Ratios or Relative Risks of falls occurring, a logical approach given their prospective study designs and recording of actual falls incidences, but some based their analyses on Odds Ratios. Odds Ratio can be more difficult to interpret than Relative Risk, and also can be misleading if interpreted similarly to Relative Risk values in high-risk populations [27, 28], making comparison of results between studies more challenging. Many studies presented sensitivity and specificity values for assessment tools, which can tell clinicians how helpful these tests may be in ruling out or ruling in the possibility of an individual being at risk of falls but, unlike positive and negative predictive values, they do not indicate the actual probability of falling and so may be less useful to clinicians overall [29]. A more standardised approach to reporting the utility of assessment tools in future studies would be helpful to clinicians and academics alike.

Discussion

Clinic-Based Assessments

The TUG is a quick and simple measure used to assess fall-risk in practice, with individuals who take more than 13.5s to complete the test often classified as being at risk for falls [30]. Its popularity both clinically and in research is reflected in this review, as it was the most frequently studied measure, being used in 13 of the studies reviewed. In the studies reviewed, cut-off times between 12 and 13s were found to predict falls with moderate to high sensitivity and specificity in some samples [26, 31, 32]. Some studies indicated that slightly lower [15, 33-36] or higher [22, 37, 38] cut-off times may be required to accurately predict future falls, although these discrepancies may simply reflect the variability in functioning of different samples of community-dwelling older adults. Pooled reference times of 8.1s to 11.3s have been described for healthy older adults in distinct age categories [39]. When considered in relation to the findings of this review, it appears that individuals completing the TUG in approximately 12s or more may be at risk of future falls. From a practical standpoint, using a cut-off time close to this value could enable clinicians to identify at-risk clients in a quick and inexpensive manner. It must be noted that the TUG only measures how quickly an individual can complete the task, and does not necessarily consider the quality or safety of the performance. As such, it may be of most value to clinicians as part of a comprehensive fall-risk assessment.

Like the TUG, the FTSS is another simple means of predicting falls, since most fallers take longer to complete the test than non-fallers [16, 40]. The FTSS is a quick test that requires little equipment and can be performed in small spaces; therefore it may be useful in a variety of clinical settings. Buatois et al. [34] selected 15s as the cut-off time for identifying recurrent fallers based on their previous work [41]. This is supported by the results of Doi et al. [40] and inferred from 2 studies in which the FTSS did not predict falls, since the average FTSS times were less than or close to 15s in those samples [42, 43]. Inability to complete the test was shown to predict single and multiple falls [44-46], and also future need for assistance in carrying out activities of daily living e.g. bathing, dressing, and eating [20]. The FTSS is therefore a highly useful tool for clinicians to include in their battery of fall-risk assessments.

Assessing an individual's ability to maintain various standing postures appears to be a simple yet effective method of predicting future falls. Maintaining one-legged balance for less than 5 seconds was found to predict recurrent falls [34], although a separate study found that sensitivity and specificity values for this test were low to moderate [47]. Beauchet et al.'s [47] study noted that observed changes in arm position during the first 5 seconds of the task was a more sensitive and specific predictor of recurrent falls. For clinicians, it may be helpful to document both time and any observed changes in arm position as measures of performance in this task. Failure to maintain tandem stance for 3 seconds [44] or 10 seconds [42, 48] was also found to predict single and multiple falls, with one exception [46]. For clients who are unable or unwilling to attempt single-leg stance, this may be a useful alternative test. The predictive value of the Romberg test was unclear based on the studies reviewed, as only 2 studies examined its use and they differed in their conclusions: Olsson Muller et al. [32] found that no variation of the test showed predicitive validity, whereas Stalenhoef et al. [49] found that a positive Romberg test was indicative of increased odds of falling (OR=3.7, 95% CI 1.8-7.8).

All studies that examined gait speed found it to be predictive of falls. Slow gait speeds – particularly speeds under 0.6m/s – were associated with greater fall-risk [38]. However, both Quach et al. [50] and Kelsey et al. [45] noted similarly high proportions of fallers among groups with slow (<0.6m/s) and fast (>1.3m/s) gait speeds, while fewer fallers were noted among those with speeds of 0.6-1.3m/s, a group which made up the majority of the cohort. This suggests a U-shaped relationship between gait speed and falls. Kelsey et al. [45] also showed a difference in the environmental context of these falls – the slow group fell indoors more often whereas the fast group experienced more outdoor falls. This may reflect the environments in which these groups are most active, and hence most at risk, and may be important to consider when educating clients regarding fall-risk reduction strategies. Notably, the methods of measuring gait speed varied between studies. Most studies measured usual gait speed, but some measured maximal speed [16, 21]. The distance over which gait speed was calculated also varied, from 4 metres [38, 45, 50] to 8.1 metres [21], with variations in the use of standing starts or rolling starts. Although there appears to be no clear consensus on the optimal protocol for measuring gait speed, it is still clear that it may be a useful predictor of falls. This flexibility may be helpful in practice, as clinicians can adopt the most feasible gait speed measurement protocols for their clinical environments while still obtaining a good estimation of fall-risk.

The BBS is a widely-used, valid and reliable outcome measure [51]. However, only 1 of the 6 studies reviewed identified it as a useful predictor of falls [45]. The lack of predictive value seems to be due to a ceiling effect. A cut-off score of less than 40 is intended to indicate moderate fall-risk [52], but many studies reported mean scores or ranges of scores for their samples close to the maximum score of 56 for the BBS [23, 33, 35, 36], despite the fact that these groups experience falls. This suggests that the BBS is not sufficiently challenging to predict falls in a general older community-dwelling population. It may be useful among groups with more apparent balance and mobility deficits not considered in this review e.g. individuals recovering from hip fractures [53]. Clinicians should therefore consider using other more appropriate methods to predict falls in community-dwelling older adults who do not display marked balance and/or gait deficits.

Although included as a component of the BBS, the Functional Reach Test (FRT) was also investigated as a stand-alone measure in five of the studies reviewed. Results were inconsistent, with Stalenhoef et al. [49] finding that a functional reach of ≤15cm approximately doubled the risk of falling, while other studies showed that neither functional [37, 54] nor lateral reach [23] could prospectively discriminate between fallers and non-fallers. Butler et al. [55] found that those with poor maximal reach distances were more prone to falls, and also tended to incorrectly judge their own reaching ability. This error between estimated and actual reach distance was found to discriminate between recurrent and non-recurrent fallers with an 83.5% success rate in a separate study [37], and may be a useful addition to this assessment tool which could be easily incorporated in practice to improve its predictive value.

Two other clinical assessments tools, the Dynamic Gait Index (DGI) and Performance-Oriented Mobility Assessment (POMA), were evaluated in four studies and three studies, respectively. Despite assessing gait as opposed to predominantly static balance, the DGI appears to be subject to a similar ceiling effect as the BBS among high functioning older adults, with most studies not supporting its predictive value [33, 35, 36]. However, it can be a highly sensitive and specific predictor of falls among individuals with gait deficits who score poorly [26], so clinicians may find it useful for clients who have specific gait concerns. Mixed results regarding the POMA were observed [48, 54], and some doubts regarding its sensitivity in predicting injurious falls were raised [21]. This may be considered a significant weakness, since sensitivity may be more important than specificity in a fall-risk measure i.e. it may be more pertinent for clinicians to recognise those who require intervention than those who do not [21].

As seen in Table 1, a wide range of other clinical assessment tools were used in insufficient numbers of studies to allow conclusions to be drawn on their effectiveness in predicting falls. Some of these tools e.g. Balance Outcome Measure for Elder Rehabilitation (BOOMER) [25], Short Physical Performance Battery [45], combine other assessment tools or facets of them to create composite ordinal measures. While this may potentially enhance the value of the selected tasks, other issues may arise e.g. the selection of appropriate cut-off points for scoring, the potential for ceiling effects when using an ordinal rather than a continuous measure, which can make such assessment tools difficult for clinicians to interpret and apply across a range of clients in practice.

Laboratory-Based Assessments*.*

Postural Sway.

Postural sway was assessed under a variety of different conditions in the studies reviewed, predominantly using force plates to monitor movements of the body's centre of pressure in standing. Overall, greater postural sway was associated with increased fall-risk, although the sway-related variables of interest varied between studies. One study cited abnormal sway as a useful predictor of falls, although the definition of abnormal sway and the methods of measuring sway were not adequately described [49]. In other cases, measures of sway amplitude (56), total length of sway [43], sway area and excursion [21] were all found to predict falls. Most studies focused on medio-lateral (frontal plane) sway [23, 43, 56], but sway in the antero-posterior (sagittal plane) direction was also seen to be predictive of falls [22]. These findings indicate that greater sway can broadly be said to predict falls, although the variations in the measurement protocols adopted and the sway variables analysed make it challenging to compare the results of studies and do not allow definitive conclusions to be drawn on the optimal protocols, variables and precise sway values for falls prediction.

Gait Analysis.

Gait was analysed in the reviewed studies using varying technologies, including force-sensitive insoles [17, 36, 54], instrumented walkways [57, 58] and body-worn sensors [40, 59]. Similar to the clinic-based assessment, a U-shaped relationship between gait speed and multiple falls was observed, both at participants' usual walking speed [58] and fast walking speed [57]. A low cadence was shown to predict falls [59], although a U-shaped relationship may also exist in this case [58]. Step length may also be a useful marker, since greater step length variability was found to predict greater fall-risk [58]. The relationship between step length and cadence could be used to characterise those at risk of falling, since those with a shorter step length and higher cadence when attempting fast walking – indicating a shuffling pattern – were seen to have a greater risk of multiple falls [57]. Gait variability measures – specifically variability of overall step time, double-support phase time [58], stride time and swing time [54] – were also found to predict falls, as did swing time variability under dual-task conditions [17]. At present, the equipment required to record such gait parameters may not be available to clinicians working outside of specialist gait laboratories. However, one recent novel study used small body-worn accelerometers to successfully predict future faller status, with fallers demonstrating less stable and smooth trunk movements during gait [40]. Such devices could provide a convenient means of objectively analysing gait outside the laboratory setting, as well as quantifying performance on a range of other fall-risk assessment tasks, although the clinical utility of these devices is not yet well established and further studies are required to determine their potential applications in clinical practice [60].

A wide range of additional laboratory-based measures were also examined. In single studies, lower limb stepping reaction times did not distinguish between fallers and non-fallers [23], but upper limb reaction times when dual-tasking were slower among fallers [24]. Other single studies examined lower limb muscle activation patterns [23], motion analysis of 360° turns [61] and reactions to experimentally-induced slips [15] with some promising results, but there is insufficient evidence from the studies reviewed to reach conclusions on their value as predictors of future falls.

Limitations

Although every effort was made to ensure the search was as extensive and inclusive as possible, some potentially relevant articles may have been omitted in error. Articles which dealt with assessment methods not based on actual performance of tasks were not included. Although this may be considered a limitation given the multi-factorial nature of fall-risk, it was the intention of this review to focus on this particular aspect of falls prediction. A number of previously-published reviews deal with the overall assessment of fall-risk among older adults [2, 10, 12, 62].

Only studies which prospectively monitored falls incidence were included in this review, therefore a considerable amount of evidence from retrospective studies was not considered. However, the aim of this review was to determine the value of assessment tools in predicting future falls, rather than discriminating between those with and without a history of falls, and prospective studies were deemed to be the optimal design to meet this aim.

Due to the inclusion criteria for this review, assessment tools designed for use in populations with specific conditions or in settings other than the community were not reviewed. Some such tools may also be useful in a general community-dwelling population, although until research has been carried out to confirm this, it is not possible to confirm or refute their value.

Conclusions

This review identified numerous task performance-based assessment tools which can predict falls in community-dwelling older adults – both clinic-based and laboratory-based. In terms of clinic-based tools, the TUG, FTSS and measures of gait speed all displayed strong evidence that they can predict falls incidence in this population. Some evidence for tests of standing balance and reaching task performance was also found. Laboratory-based measurements of postural sway and gait variability were also found to predict falls, despite a lack of consistency in the reported protocols for assessing these variables. A feasible means of assessing these variables in clinical practice – e.g. via the use of body-worn sensors – may improve the accuracy with which clinicians can predict falls among their clients, although further prospective studies using rigorous falls reporting methods are required to confirm this. The studies included were largely of high methodological quality, thus the findings of this review can help to guide clinicians in the selection of the most valuable tests for predicting falls among older adults in the community. Incorporating the recommended assessment tools into a comprehensive overall assessment can lead to improved client care and more efficient practice.

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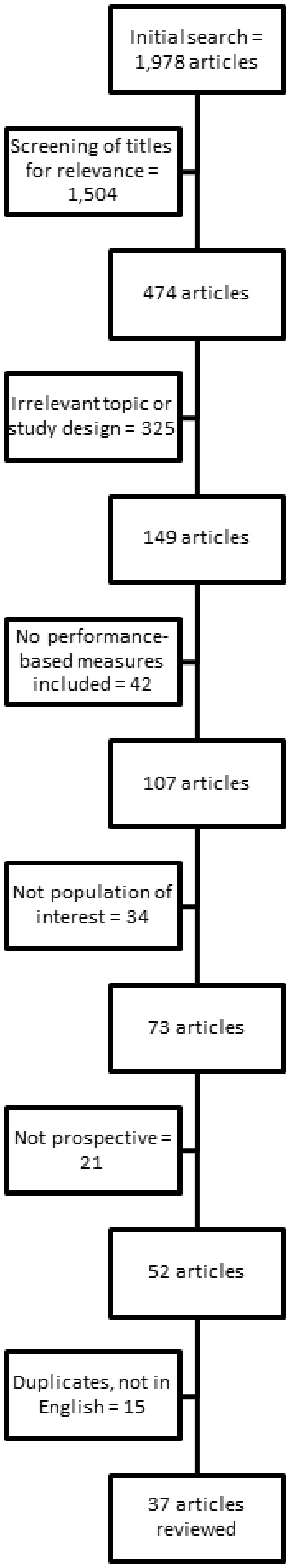

Figure 1. Flow diagram illustrating the literature search and screening process.

Table 1

Assessment tools and falls reporting methods.

Author(s)	**N**	**Tool(s)**	**Tool Type**	**Falls Reporting**	**Follow-Up Period**	**Results**
Alexandre et al. [31]	63	TUG	Clinical	Falls log collected at 3, 6 and 12 months	12 months	Optimal cut-off time = 12.47s (73.7% sensitivity, 65.8% specificity) RR=3.2; 95% CI: 1.3-7.7
Aoyama et al. [22]	58	BBS TUG Force plate measures during standing	Both	Monthly falls calendar	6 months	Fallers displayed greater mean AP sway during bipedal stance than non-fallers (OR = 1.26, 95% CI 0.98-1.63)
Beauchet et al. [47]	1759	OLB	Clinical	Monthly telephone call	12 months	OLB time <5s: 33.3% sensitivity, 58.2% specificity Change in arm position during first 5s of OLB: 55.9% sensitivity, 71.2% specificity

Boulgarides et al. [33]	99	BBS TUG DGI Modified CTSIB	Both	Monthly falls calendar	12 months	1 aspect of modified CTSIB (standing on firm surface, eyes closed) predicted 1 in 20 multiple fallers
Brauer et al. [23]	100	BBS FRT Lateral reach test Step-up test Standing force plate measures LL reaction time LL EMG	Both	Monthly falls calendar	6 months	Clinical balance tests did not predict fallers. A combination of variables from the laboratory tasks provided the best overall prediction rate (77%) of fallers (sensitivity 51%) and non-fallers (specificity 91%)
Buatois et al. [34]	1618	TUG FTSS OLB	Clinical	Recall at follow-up	18-36 months	Twice as many recurrent fallers among participants who completed the FTSS in >15s compared to those who took ≤15s in the moderate fall-risk group (18% v 7%)

Butler et al. [55]	415	Maximal reach	Clinical	Monthly falls calendar	12 months	Poor performers (maximal reach 78.6 ± 0.3 cm) had a higher rate of falls per person (approx. 1.4 95% CI 1.2-1.6) than other groups
Callisaya et al. [58]	412	Gait and gait variability (computerised walkway)	Lab	Falls calendar and bi-monthly postal questionnaire	12 months	RR of multiple falls increased with increasing step length variability (*P* = 0.03) and double-support phase variability (*P* = 0.02) Non-linear relationships between multiple falls and gait speed (*P* = 0.002), cadence (*P* = 0.004) and step time variability (*P* = 0.03)
Callisaya et al. [57]	176	Gait variables (computerised walkway)	Lab	Falls calendar and bi-monthly postal questionnaire	12 months	Risk of multiple falls greater for those with a smaller walk ratio (shorter steps, faster cadence) during fast-walking (RR 0.92, 95% CI 0.87, 0.97) and greater reduction in walk ratio (smaller increase in step length, larger increase in cadence) when changing to fast-walking (RR 0.73, 95% CI 0.63-0.85)

						Quadratic relationship between fast walking speed and multiple falls, with highest rate in fastest group (1.76-2.6 m/s; RR 2.75; 95% CI 0.44-17.13)
Chan et al. [16]	5995	FTSS Gait speed (6-metre walk, usual and narrow stance width)	Clinical	4-month recall, 3 times per year	4.5 years	The slowest quartile for the FTSS had a higher risk of falls than the fastest (RR 1.25, 95% CI 1.12-1.39). The fastest narrow walkers had reduced risk of falls compared to the slowest quartile (OR 0.83, 95% CI 0.73-0.94)
Chu et al. [48]	1517	POMA Gait speed (5-metre walk) Standing balance tests	Clinical	Bimonthly telephone interview	12 months	Gait speed (RR 0.23, 95% CI 0.11-0.50, *P* <0.001) and failure to complete tandem stance (RR 1.61, 95% CI 1.17-2.23, *P* = 0.004) were predictive of ≥1 falls POMA score was predictive of recurrent falls (RR 0.92, 95% CI 0.88-0.97, *P* <0.001)

Delbaere et al. [18]	500	PPA Coordinated stability test OLB 6-metre walk (with turn)	Clinical	Monthly falls diaries with telephone reminders	12 months	Fallers performed more poorly in terms of PPA score (OR 1.31, 95% CI 1.06–1.61), coordinated stability error score (OR 1.21 95% CI 1.00–1.46) and OLB time (OR 0.80, 95% CI 0.67–0.97)
Doi et al. [40]	73	FTSS TUG Trunk accelerations during 10-metre walk	Both	Weekly interview	12 months	Non-fallers performed better than fallers on FTSS (fallers: 19.6 ± 9.4s; non-fallers: 13.8 ± 5.7s; *P* = 0.037) and TUG (fallers: 20.7 ± 10.6s; non-fallers: 14.1 ± 7.5s; *P* = 0.031). Harmonic ratios of upper and lower trunk accelerations were significantly lower in fallers than non-fallers
Faulkner et al. [42]	8378	FTSS Gait speed (6m walk)	Clinical	Recall postcards/telephone calls every	4 years	Faster usual gait speed associated with increased falls risk (RR = 1.18; 95% CI 1.08-1.30). Good standing balance protective (RR=0.73,

		Standing balance tests		4 months		95% CI 0.6-0.81)
Graafmans et al. [44]	354	FTSS Tandem stance (<3s) Observational gait analysis (6m with turn)	Clinical	Falls diary	7 months	FTSS failure increased single falls (OR=2.5, 95% CI 1.5-4.1) and multiple falls risk (OR=4.8, 95% CI 2.5-9.3) TS failure increased single falls (OR=2.4, 1.5-3.9) and multiple falls risk (OR=3.7, 1.9-7.3). Observed gait abnormalities increased single falls (OR=2.6, 1.6-4.3) and multiple falls risk (OR 5.3, 2.8-10.0).
Hausdorff et al. [54]	52	TUG POMA SPPB FRT Gait variability using force-	Both	Weekly telephone report	12 months	Falls predicted by stride time variability (OR=5.3, 95% CI 1.01–27.2) and swing time variability (OR=2.2, 95% CI 1.1–4.4)

		sensitive insoles (6min walk)				
Herman et al. [17]	262	Gait characteristics using force-sensitive insoles (single- and dual-task)	Lab	Monthly falls calendar	2 years	Dual-task swing time variability (OR=1.26, 95% CI 1.03-1.55) predicted falls
Herman et al. [35]	265	TUG BBS DGI	Clinical	Monthly falls calendar	3 years	Multiple fallers took longer ($p = 0.035$) to complete the TUG at baseline (10.3 ± 1.9 s), compared to non-fallers (9.5 ± 1.7 s) BBS and DGI not related to faller status
Inoue et al. [37]	85	TUG FRT Gap between	Clinical	12-month recall	12 months	GAE was related to recurrent falls (OR 1.09; 95% CI 1.01-1.17). 83.5% success rate discriminating between recurrent fallers and non-recurrent

		actual and estimated reach distance (GAE)				fallers
Kelsey et al. [45]	765	BBS SPPB FTSS 6MWT Gait speed (4m)	Clinical	Falls calendar	2 years	Increased falls incidence in those scoring 48-50 (IRR 1.33, 95% CI 1.04–1.69) or <48 (IRR 1.44, 95% CI 1.10–1.89) on BBS relative to those who scored ≥51. Failure to complete FTSS predictive of indoor falls (IRR 1.85, 95% CI 1.20–2.86) Decreased falls incidence in those with gait speeds of 0.68-1.33m/s (IRR 0.59, 95% CI 0.41–0.87) and <0.68m/s (IRR 0.69, 95% CI 0.43–1.10) relative to those with gait speeds ≥1.33m/s
Lord et al. [59]	96	Gait analysis (instrumented walkway)	Lab	Bi-monthly postcards/telephone interviews	12 months	Multiple fallers had significantly lower cadence, greater cadence SD, greater stance time and stance percentage than non-fallers or single

						fallers
Makizako et al. [24]	45	Reaction times under dual and triple-task conditions	Lab	Recall questionnaire at follow-up	5 months	Fallers had significantly slower reaction times than non-fallers under both dual-task conditions (dynamic balance and cognitive), but not in triple-task condition
Morrison et al. [25]	205 outpt., 314 dom.	BOOMER (Balance Outcome Measure for Elder Rehabilitation)	Clinical	Weekly interviews throughout length of stay	Outpatient mean days (SD) = 51.5 (38.1) Domiciliary mean days (SD) = 47.7 (39.4)	Lower BOOMER scores significantly associated with falls: Outpatient IRR 0.82 (95% CI 1.07-1.09), *P* < 0.01 Domiciliary IRR 0.80 (95% CI 0.69-0.94), *P* = 0.01
Olsson Muller et al. [32]	85	TUG Romberg test (+ semi-tandem	Clinical	3-month falls recall via interviews at 6	12 months	TUG suggested cut-off of ≥12–13s: 67% sensitivity, 50% specificity at 6 months; 78% sensitivity, 37% specificity at 12 months

		and tandem variations)		and 12 months		No variation of the RT showed acceptable predictive validity
Pai et al. [15]	13	TUG Reaction to experimental slips on sit-to-stand	Both	12-month recall at follow-up	2.5 years	TUG time >9s: 50% sensitivity (95% CI 9.2,90.8) , 56% specificity (95% CI 40.2,96.1) Slip score >6 (maximum 14): 75% sensitivity (95% CI 21.9,98.7), 89% specificity (95% CI 50.7,99.4)
Panzer et al. [21]	74	POMA Gait speed (8.1m) Sensory Organisation Test Force-plate measures: Maximal lean Romberg Test Sit-to-Stand	Both	Weekly postcards	12 months	POMA predicted fall status with 51% sensitivity and 100% specificity. Sensory Organisation Test: 32% sensitivity, 93% specificity. Fallers were significantly slower than non-fallers in gait speed, turning and stepping tasks, had a shorter maximal lean and greater sway during quiet standing and sit-to-stand

		Turn and sit Stepping into bathtub Walking down 3 steps				
Quach et al. [50]	600	Gait speed (4-metre walk)	Clinical	Monthly falls calendars	18 months	Participants with faster (>1.3 m/s) (IRR 2.12, 95% CI1.48–3.04) and slower (<0.6 m/s, IRR 1.60, 95% CI 1.06–2.42) gait speeds at higher risk of falls than those with normal gait speeds (1.0–<1.3 m/s)
Srygley et al. [36]	266	BBS TUG DGI Pull test Swing time & variability	Both	Monthly falls calendar	12 months	Higher TUG time significantly associated with multiple falls (*P*=0.035)

Stalenhoef et al. [49]	311	FRT GUGT Romberg test Postural sway Bending down test Trendelenburg test	Both	Recall every 6 weeks via telephone interview	9 months	Positive Romberg test (OR=3.7, 95% CI 1.8-7.8), GUGT score ≥3 (OR=3.6, 95% CI 1.6-7.4) and FRT ≤15cm (OR=2.0, 95% CI 1.0-3.9), abnormal postural sway (OR=7.2, 95% CI 2.7-19.2), Trendelenburg test (OR=1.5, 95% CI 0.8-2.9) and performance on bending down test (OR=2.5, 95% CI 1.1-5.9) associated with recurrent falls
Stel et al. [43]	439	FTSS Walking test Postural sway Tandem stand	Both	Monthly falls calendar	12 months	Walking test (OR = 2.2; 95% CI 1.1–4.1), ML sway (OR = 2.8; 95% CI 1.1–6.9) and tandem stand (OR = 2.1; 95% CI 1.1–3.8) associated with recurrent falling
Swanenburg et al. [56]	270	Standing balance force plate variables	Lab	Monthly falls calendar	12 months	Root mean square amplitude in the ML direction predicted multiple falls in the single-task condition (OR 21.8, 95% CI 3.2-149.3)
Tromp et al. [46]	1285	FTSS	Clinical	Weekly falls	12 months	FTSS performance predicted falls (OR=1.2 per

		Walking test Tandem stance		calendar		point decrease, 95% CI 1.1–1.4) and recurrent falls (OR=1.4 per point decrease, 95% CI 1.2–1.6)
Viccaro et al. [38]	457	Gait speed (4-metre walk) TUG	Clinical	Face-to-face recall at 3-month intervals	12 months	Both TUG and gait speed demonstrated similarly acceptable predictive values for multiple falls
Wright et al. [61]	35	Motion analysis of standing 360° turns	Lab	Monthly falls questionnaire	12 months	Fallers differed from non-fallers in pelvis onset (*P* = 0.002); mean angular separation in the transverse plane between the head and trunk (*P* = 0.018); peak angular separation in the transverse plane between the trunk and pelvis (*P* = 0.013); and mean angular separation between the trunk and pelvis (*P* < 0.001)
Wrisley and Kumar [26]	35	FGA DGI TUG	Clinical	Monthly falls calendar	6 months	FGA score ≤20 predicted fallers with 100% sensitivity and 83% specificity DGI score ≤20: 100% sensitivity and 76%

						specificity TUG ≥12.3s: 83% sensitivity and 97% specificity
Yamada and Ichihashi [63]	171	Trail-Walking Test (TWT)	Clinical	Monthly telephone interview	12 months	TWT performance could correctly classify 77.8% of fallers; 66.1% sensitivity, specificity 83.9%
Zhang et al. [20]	562	FTSS	Clinical	12-month recall at follow-up	3 years	Inability to complete the FTSS did not significantly predict falls (OR 4.22, 95% CI 0.82-21.71, *P* = 0.09)

Note. N = number of participants, TUG = Timed Up and Go Test; BBS = Berg Balance Scale; OLB = One-Legged Balance; DGI = Dynamic Gait Index; FRT = Functional Reach Test; CTSIB = Clinical Test of Sensory Organisation and Balance; LL = Lower Limb; EMG = Electromyography; FTSS = Five Times Sit-to-Stand Test; POMA = Performance-Oriented Mobility Assessment; PPA = Physiological Profile Assessment; SPPB = Short Physical Performance Battery; 6MWT = 6 Minute Walk Test; GUGT = Get Up and Go Test; FGA = Functional Gait Assessment; RR = relative risk; 95% CI = 95% confidence interval; OR = odds ratio; *P* = significance value; IRR = incidence rate ratio; SD = standard deviation; AP = antero-posterior; ML = medio-lateral; outpt. = outpatients; dom. = domiciliary.